A TWO-DIRECTIONAL FOCUSSING HIGH-INTENSITY MASS-SPECTROMETER

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ABSTRACT. A two-directional focusing high-intensity mass-spectrometer of focussing angle $\sqrt{2}\pi$ with mean radius 381 mm, variable 20 KV accelerating voltage, is described. Focusing properties and performance with a magnetic oscillation type ion source for gases are studied so that the instrument may be useful for studies of collision of ions in gases and solids, for preparation of isotope targets and β-sources by direct deposition method.

INTRODUCTION

High-intensity mass-spectrometers or low-intensity electromagnetic isotope separators have recently become very important tools for research and many such instruments with ion currents ranging from 10^{-7}A to 100 μA have been constructed in different laboratories. Koch (1958) has reviewed these instruments, constructed so far and their application in laboratories for nuclear research In the present paper we shall describe the constructional details of the development of a high-intensity mass-spectrometer consisting of a two-directional focussing magnetic analyser with a preliminary report of its performance

THE MAGNETIC ANALYSER

The magnetic analyser, the main component of the mass-spectrometer, is designed after the β-ray spectrometer, originally constructed by Siegbahn and Svartholm (1946) with some modifications. The choice of such two directional focussing $\sqrt{2}\pi$ magnet over other types for high-intensity mass spectrometry was dictated by the following considerations

1) The axial focusing property of the analyser is of great advantage since it enables the direct deposition of β-ray sources or targets without any appreciable loss of the source materials used in the ion source.

2) The dispersion of such magnetic analysers is higher than that of the homogeneous magnetic analysers or the inhomogeneous ones as used by Zilverschoon (1954) and Artsimovich *et al* (1957)

3) In spite of the disadvantages of the aberration factor which is higher for the two directional focussing magnetic analysers than the third order focussing, one, used by Zilverschoon (1954) the simplified conical shape of the pole faces

used by Arbman and Svartholm (1955) for a β-ray spectrometer or by Snyder *et al.* (1950) for a nuclear spectrometer could more easily be attained than shaping the inhomogeneity in the pole faces for third order focussing

4) The accommodation of the ion source would have been convenient with a 180°-two directional focussing magnetic analyser described by Snyder *et al.* (1950) However with a $\sqrt{2}\pi$ focussing angle, the loss of ions is minimum and without any special device, space charge elimination can be accomplished with the electrons produced by the ion beam in collision with the residual gas as has been discussed by Zilverschoon (1954), since ions do not travel any distance out of the magnetic field.

The dimensions and the constructional details of the analyser with the focus-

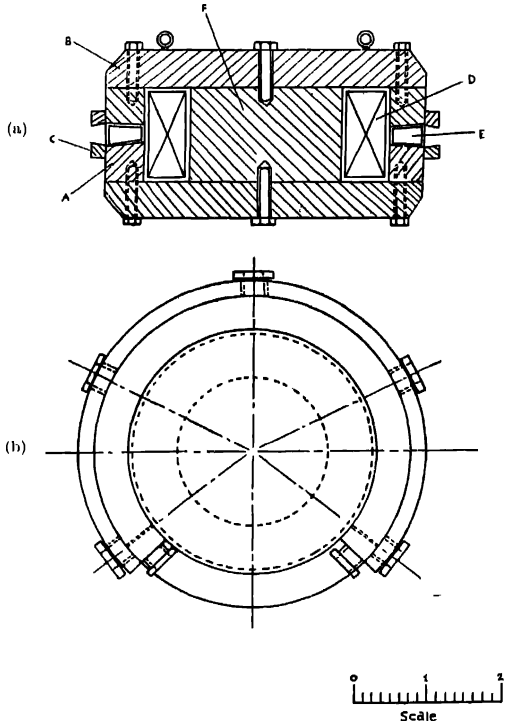

Fig. 1 – (a) Vertical section of the magnetic analyser with chamber ; A and C—pole pieces with extension, B—yoke; D—coil; E - chamber.
(b) Horizontal section of the magnetic analyser with the vacuum chamber.

sing properties of the pole faces were previously described by the author (1959). The mean radius for the ions is kept at 381 mm at a gap width 5 cm as shown in Fig. 1(a) and 1(b) The vertical and horizontal sections of the magnetic analyser are shown in 1(a) and 1(b) respectively, along with the vacuum chamber

In addition to the vacuum system described by the author (1959), a four-inch diffusion pump is now used on the ion source side for differential pumping of the residual gases and vapours. Both the diffusion pumps are operated with freon cooled baffles, so that the pressure of the chamber is maintained at $\sim 1 \times 10^{-5}$mm Hg. when the ion source is operated with a gas Liquid air traps are also provided to reduce the condensable vapours The pressure is measured with thermocouple, penning and ionisation gauges

THE ION SOURCE

A magnetic oscillation type ion source for gases is used with axial extraction as described by Nielsen (1957). The ion source (Fig 2) consists of a ribbon filament (G), tips of which are water cooled, a cylindrical anode (H) of graphite with a 3/16 inch hole for the outlet of ions and outlet side is tapered at an angle of

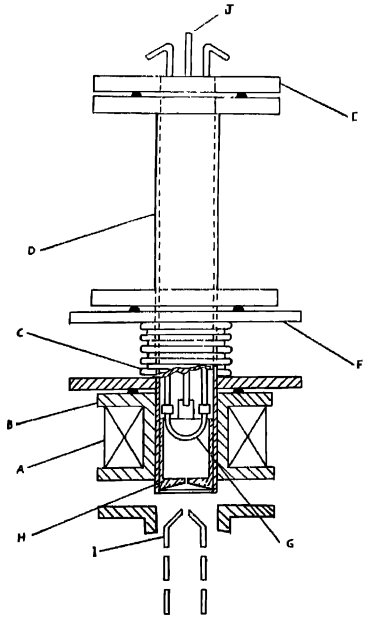

Fig. 2. Diagram of the ion source and the focussing electrodes.

55°. The whole system is on a brass flange (E) with electrical leads hermetically sealed. The tubular lead (J) connecting the anode serves as gas inlet adjustable through a needle valve. The source with flange is placed within a double-flanged specially made vitreosil tube (D) and made vacuum tight with rubber O-rings. One flange of the vitreosil tube is connected to the main vacuum chamber through a bellow (C) for slight adjustment of the system in space and a brass cylinder (B) containing the solenoid (A) for producing an axial magnetic field $\sim$ 200 gauss for operating the ion source.

Three co-axial iron cylinders over the solenoid have to be used with spacers for screening the magnetic field of the main analyser, which might disturb the arc of the ion source. The ions are extracted through an electrode system consisting of three graphite cylinders, the first one (I) kept at a potential $\sim$ 1500 V, which can be varied for attaining the optimum condition. The second one is kept at a potential 0.75 V, where V is the accelerating voltage and the third cylinder is at earth potential. Ions are electrostatically focused through this lens system and deflected by the magnetic analyser. The operating pressure in the source chamber is kept at $\backsim 10^{-2}$ to 10^{-3} mm Hg approximately

ELECTRONIC EQUIPMENTS

Resolving power of a mass- spectrometer greatly depends upon the stability of the magnetic field and the accelerating voltage. For attaining a specified resolution, the order of voltage stability required is only half of that of the magnetic field i.e. $\frac{\Delta H}{H} = \frac{\Delta V}{2V}$. So, it was decided to stabilise the magnetic field to 1/2000 and the accelerating voltage power supply to 1/1000 In stabilising the magnetic field, the current passing through the exciting coil is usually stabilised. For high impedance coils (D.C. 800 Ω resistance) of our magnetic analyser, a stabilised

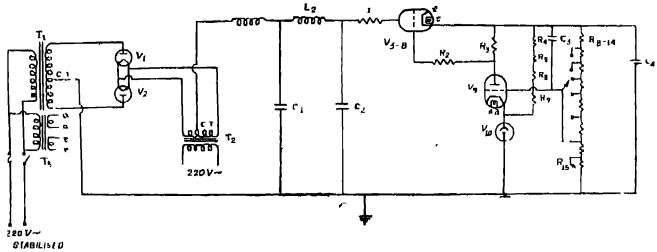

Fig. 3. Stabilised power supply for the magnet coils:
T_1—Pri 220v, Sec 2000—0—2000v; 1 5A; T_2—Pri 220v, Sec 2,5–0–2,5v, 30A; T_3—Pri 220v, Sec 6 3v, 3A; 2.5v, 5A; L_1, L_2—20H, 1.5A ins. 2KV; C_1, C_2—16 μfd, 2500v D.C; C_3—1 μfd, 2KV D.C.; C_4—4 μfd, 1500V D.C.; V_1, V_2—872A, V_{3-8}—6336 (6); V_9—2C53, V_{10}—5651; R_1—100Ω, R_2—2KΩ, R_3—4MΩ, R_{4-7}—100KΩ, R_{8-14}—100KΩ, R_{15}—100KΩ Helipot (ten turns).

power supply was considered sufficient to attain short period stability of the magnetic field. Fig. 3 shows the circuit diagrams of the stabilised power supply +200 to +1500 V at 1.25A used for exciting the magnet coils. The use of 6336 (Chattham) series control tubes, high mu triode 2C53 as amplifier and 5651 as reference tube gives a stability of ~ 1/2000 to the magnetic field over the mains fluctuations stabilised to 0.2%, with an a.c. stabiliser (G.R). For a better stabilisation, a second feedback stage similar to that used by Pelchowich (1954) or to avoid long time instability a current stabilisation device will be required. For the present, neither of these improvements have been considered.

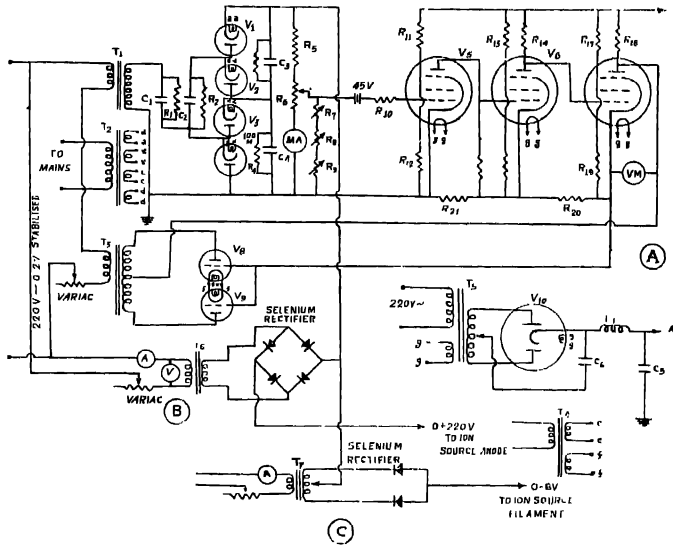

Fig. 4. Power supply for the ion source:

(A) Accelerating voltage 0-20KV (stabilised), (B) Arc voltage, (C) Filament heating supply, T_1—Pri 220v, Sec 0-5KV, 50 mA (ins. 25KV), T_2—Pri 220v, Sec 2.5-2.5, 10A (4) (ins. 25KV), T_3—Pri 90v, Sec 400-0-400, 100mA, T_4—Pri 220v, Sec 0-2 5v, 5A (2), T_5—Pri 220v, Sec 350-0-350, 6 3v, 5A, T_6—Pri 220v, Sec 0-8v, 100A, T_7—Pri 220, Sec 0-220v, 2A, L_1—5H, 100mA, C_1, C_2, C_3, C_4—0.5 μfd, 10 KV D.C., C_5, C_6—2 μfd, 500V, D.C., V_{1-4}—8020, V_{5-7}—6J7, V_{8-9}—2A3, V_{10}—6X5, R_{1-5}—100MΩ, R_6—1KΩ, pot, $R_{7,8}$—1MΩ, pot. R_9—125Ω, pot., $R_{10,11}$—0.4MΩ, $R_{12,13}$—0.1MΩ, R_{14}—0.4MΩ, R_{15}—0.1MΩ, R_{16}—30KΩ, R_{17}—10KΩ, R_{18}—100 KΩ, R_{19}—2.5KΩ, R_{20-21}—2KΩ,

The 0 to +20 KV accelerating voltage power supply (Fig. 4) is a quadrupler rectifier from a 5 KV transformer, the primary of which is supplied with 0.2%

stabilised 220V A.C. The output d.c. 0 to +20 KV is stabilised to 1/1000 with a circuit (Fig. 4) similar to that described by Hanson (1944) and modified to some extent.

The filament heating power supply (Fig. 4) consists of a 8V, 100 A. A. C voltage, stabilised to 1% and rectified with a selenium rectifier The arc voltage is supplied from a 0 to 220V, 2A transformer with 0.2% stabilised A.C. voltage and rectified with a selenium rectifier (Fig 4).

For oscilloscope detection of the ion beam, a special type of transformer with proper air gap in the core and the secondary voltage variable from 0 to 1000V is connected in series with the accelerating voltage output for modulating it at 50 c/sec with other arrangments similar to described by Zilverschoon (1954).

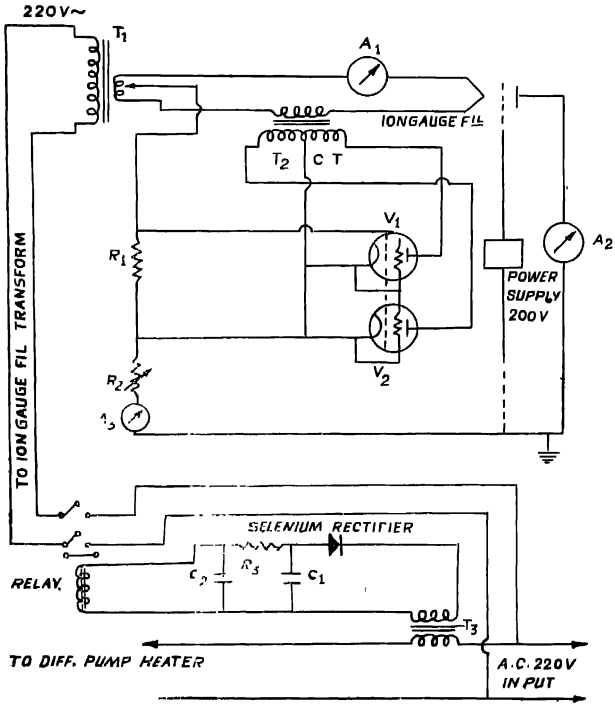

Fig. 5.—Circuit diagram for ionisation gauge with interlock for the diffusion pump. T_1—Pri 220V, Sec—6.3V, 10A, T_2—Pri 6.3V, Sec, 110–0–110V, T_3—Pri 12V—Sec 220V, $C_{1,2}$—50 μfd, 500V D.C., R_1—2KΩ, R_2—1KΩ pot., R_3—200Ω, A_1—0—10A A_2—0—10μa, A_3—0—10mA.

Fig. 5 shows the ion gauge circuit with devices for emission regulation, modified from a circuit used by Richard and Tuthil (1951).

For the safety of the ion gauge, its filament supply is interlocked with the heater supply of the diffusion pump by a circuit (Fig. 5) so that the ion gauge is protected when the heater supply breaks down. The backing mechanical pump is connected with the diffusion pump through a magnetic valve with air-admittance, which protects the diffusion pump oil from contamination with mechanical pump oil.

Fig. 6 shows a functional diagram of the mass-spectrometer with its different components.

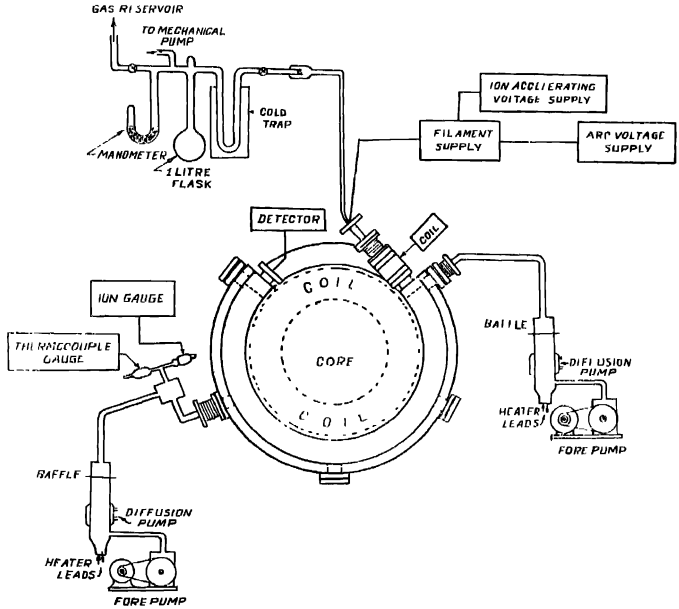

Fig. 6.—Functional diagram of the mass spectrometer.

PERFORMANCE

The performance of the massspectrometer was tested by introducing neon and krypton gas in the ion source. Fig. 7 shows the photograph of the mass-spectrum of krypton from the oscilloscope screen, obtained by sweeping the ion-beam over a slit 1/32 inch wide by modulating the accelerating voltage with the

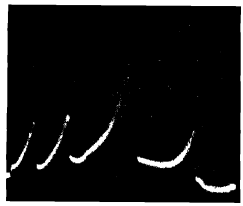

Fig. 7.—Oscillograph record of the mass spectrum of Krypton isotopes. (M = 82, 83, 84 & 86).

following operating conditions : filament power ~ 230 Watts, arc voltage ~ 70 Volts, arc current ~ 400 mA, accelerating voltage ~ 6 KV.

The oscillograph record shows some distortion due to the back-ground noise, when arc strikes and which can not be eliminated with the oscilloscope available. The current for the highest peak is estimated as ~ 10^{-7} amp. The resolving power is measured to be ~ 125, from the equation

$$R = \frac{x}{W_{\frac{1}{2}}} \cdot M$$

where x is the distance between two masses, $W_{\frac{1}{2}}$ is the half width, M is the mass number. The resolving power is found to be constant with the ions of neon and krypton for the accelerating voltage up to 8 KV, above which no reliable data at present were taken, because of the sparking between the ion source and negative electrode for extraction. Since the extraction of ions behaves as space charge limited current with this type of ion source, high accelerating voltage will enhance the focused ion beam. Moreover, the influence of the field of the main magnetic analyser over the focusing electrode, which are not fully shielded, may be somewhat responsible for the loss of the extracted current.

It is observed that the sparking is due to the rise in pressure on the ion source side and a diffusion pump of higher speed than the present one may improve the situation. Furthermore, better stabilisation of the accelerating voltage and the magnetic field, regulation of the arc, will be necessary to improve the resolving power of the instrument and the transmission may increase by modifying the ion source, extraction system and the vacuum system.

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